

AIR WAR COLLEGE

AIR UNIVERSITY

AIR TRAFFIC CONTROL CAPABILITIES: OPPORTUNITY TO UTILIZE AUTOMATED
DEPENDENT SURVEILLANCE-BROADCAST (ADS-B) EQUIPMENT ON AIRCRAFT
FOR MILITARY AIR TRAFFIC CONTROL AND COMMAND AND CONTROL IN
COMBAT AND HUMANITARIAN OPERATIONS.

by

Michael W. Helvey, Lt Col, USAF

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Biography

Upon entering the Air Force in 1990 through the Reserve Officer Training Corps at the University of Maryland, I began learning the complex global air traffic management system through wing level assignments, and later through the Department of Defense and Federal Aviation Administration acquisition processes while developing future requirements in the Air Force Flight Standards Agency. During this time I worked on a team that developed requirements for both deployable and fixed-base air traffic control systems, and represented the Department of Defense interest in the Federal Aviation Administration's National Airspace System upgrade. As follow-on to this work, I proceeded to the Air Force Operational Test and Evaluation Center, where I was fortunate enough to conduct operational test and evaluation on new voice, data, and radar systems being jointly procured by the Federal Aviation Administration and Department of Defense.

My most recent experience is in Air Force Central Command's Operations Directorate, working air command and control, airfield, air traffic, and airspace operations for the Combined Forces Air Component Commander.

Introduction

New rules being mandated by the Federal Aviation Administration (FAA), European Organization for the Safety of Air Navigation (EUROCONTROL), and other governing bodies will demand changes in navigational equipment on aircraft in order to optimize handling by national and international air traffic management systems. For example, the International Civil Aviation Organization (ICAO), to which 183 members subscribe, is including Automated Dependent Surveillance-Broadcast (ADS-B) in ICAO standards and recommended practices. The purpose of this paper is to examine this new class of aircraft equipment and propose taking advantage of this opportunity to field a deployable air traffic control surveillance capability for use across the spectrum of operations from combat to more permissive environments such as stability, reconstruction, or humanitarian operations.

Australia has already implemented ADS-B equipment requirements for aircraft flying at or above Flight Level 300 (30,000 feet above mean sea level). Australian AirServices implemented the change in order to “minimize delays, improve efficiency, and as a result reduce aircraft fuel burn and CO2 emissions.”¹ In May 2010 the United States’ Federal Aviation Administration (FAA) followed suit. The FAA has published a rule mandating all aircraft operating in the US National Airspace System (NAS) meet the avionics equipment requirements to support ADS-B by 1 January 2020.² The FAA rulemaking process included extensive deliberative opportunities in order to arrive at a compromise between the Agency, commercial operators, government operators (such as the Department of Defense), and general aviation airspace users.³

EUROCONTROL, representing 32 European nations, is implementing ADS-B under the EUROCONTROL CASCADE program. The Single European Skies draft Implementing Rule on

Surveillance Performance and Interoperability addresses all aircraft flying under instrument flight rules or general air traffic rules. According to the draft Implementing Rule, state aircraft flying in EUROCONTROL airspace must be equipped by 2017 for Mode S Emitter Locator System (ELS) with possible exemptions. By 1 January 2019, they must also be equipped for ADS-B. Canada has also mandated ADS-B⁴, and nations currently operating ADS-B ground stations, but not yet mandating avionics for airspace access include China⁵, Sweden, and United Arab Emirates.⁶ Air traffic service providers remain obliged to accommodate non-equipped state aircraft within safety limits.⁷ Even so, unless state aircraft are properly equipped, they will not be able to take advantage of the more efficient services, and will likely be penalized in terms of less preferred routing, reduced expediency, and increased fuel burn as the airspace is configured to maximize benefit to participating aircraft. There is no reason to expect nations will continue providing efficient service to non-participating aircraft as airspace becomes a more congested and high demand resource.^a

Existing System

Since the 1950s, air traffic controllers have utilized either radar or non-radar control environments. The radar environment is based on secondary surveillance radar (SSR), primary surveillance radar (PSR), or a combination of the two, along with radio communications. Non-radar service is based on pilot reports over radio of their positional data in relation to known navigational aids, geographical landmarks, or internal navigation systems. Between the

^a Non-participating and uncooperative are used interchangeably in literature when referencing aircraft that are not using equipment needed for the service provided. This is applicable to any secondary surveillance radar system that requires the aircraft to broadcast, continuously or when interrogated.

technologies, SSR is preferred to PSR and radar is preferred to non-radar due to system accuracy as described below.

Air traffic controllers apply minimum separation standards between aircraft based on the accuracy of the positional data provided by the radar or non-radar environment. The separation standard is a bubble of protection afforded to the aircraft to account for inaccuracies in position reporting, radar display, and aircraft or ground equipment. More confidence in the aircraft position affords a smaller safety bubble. Positional data includes the aircraft's three-dimensional spatial position as well as its vector. Vector includes the aircraft's heading, airspeed, and attitude (rate of climb or descent).

To provide a concrete example of the efficiencies that can be gained by improved position reporting, consider the FAA-mandated separation standards applied by air traffic controllers in the US. The short-range radar separation standard is generally 3 miles between aircraft at the same altitude or crossing altitudes. This distance is increased to 5 miles for long-range radars because of a longer time between radar updates which reduces certainty of the aircraft's position. Additionally, radar has a higher error rate the further away the aircraft is from the antenna. In a non-radar environment, separation is generally increased to 10 miles. There are many variations of the rules depending on relative aircraft speed and flight profiles.⁸ These different standards demonstrate how the standards are increased to compensate for the non-radar air traffic control system providing less accurate aircraft positional data to the controller. Likewise, long range radar separation standards are larger than short range radar standards due to the less accurate aircraft positional data presented to the controller. Therefore, the airspace efficiency (how many aircraft the system can accommodate for optimum routing in a

given airspace) is dependent on the quality and timeliness of aircraft position data, and that is dependent on the type of air traffic control system in use.

The aircraft positional data presented in a radar environment (either SSR or PSR) is derived from the radar sensor as a “plot”. Plots are correlated over time and processed into “tracks” if they display the characteristics expected of an aircraft. A track is a consistent series of plots that have passed a logical test to determine there is a probability that it is an aircraft instead of background clutter. Once this higher level of confidence has been established, it is presented to the controller in a graphical format. In a combined PSR/SSR system, the PSR track is co-located with the SSR radar data. Otherwise, it will be displayed as a primary-only or secondary-only radar track. In the most sophisticated radar systems, the processed data may be from a single sensor, or combined with data from multiple radar sources in order to improve confidence or create a larger area of radar coverage.

Although radar theory has not changed much, the processing and automation systems have progressed significantly. Early displays for air traffic control and air defense were non-processed plots presented on phosphorous decay scopes in darkened rooms, relying on the operator’s experience to pick out valid targets from clutter. Modern systems have high-resolution color displays which can present aircraft information including altitude, heading, airspeed, aircraft type, route info as well as emergency information. Data processing has gone from virtually zero (raw radar) to highly complex algorithms that present data to the controller with a very high confidence, even resolving conflicting data between two or more sensors. These software based changes are still limited by the physical hardware and radar theory employed by the sensors.

PSR or “primary radar” is 1940’s technology that relies on bouncing a high-energy radio signal off of an aircraft and receiving the echo of that signal. While advancements have been made, PSR used for either air traffic control or military command and control is still challenged to discriminate aircraft from birds, rain, sea-state, road traffic, and other “clutter”. PSR must be adjusted for the best probability of detecting a real aircraft while at the same time reducing the amount of false targets. This balancing act may be done by hardware or software on the radar itself, or within the controller’s display system, commonly called an automation system.

However, the discrimination between aircraft and clutter is difficult to optimize and never results in a fully accurate picture of aircraft within the coverage volume. In contrast to PSR, SSR uses a low-power interrogator to trigger a response from a transponder located on the aircraft to obtain aircraft identification and positional data. This active reporting from the cooperative aircraft is not subject to false targets because it only collects data based on responses from aircraft with working transponders.

In a non-radar environment—widely used in oceanic, low-density traffic areas, and mountainous regions—the data are sent to the controller via voice radio. Corresponding flight records are manually updated by the controller to build a physical or mental picture of the airspace environment.⁹ It is clear that greater data accuracy enables reduced separation and greater volume of traffic in a given amount of airspace. Therefore, improvements in data accuracy and confidence afford more economical routing to a greater number of aircraft. In general, radar (surveillance) is more efficient than non-radar (procedural) control, resulting in decreased delays and operator costs. The FAA anticipates reducing non-radar traffic in oceanic and remote airspace routes from 90NM lateral separation to 20NM separation, and longitudinal separation from 80NM to 5NM based on increased accuracy of space-based navigational systems

like Global Positioning System (GPS). Also, in some domestic overflight or terminal airspaces that currently have 5NM separation, the FAA is working to reduce separation to 3NM but will not move forward until safety and operational analysis have been completed and the system certified for that level of separation.¹⁰ Nations are also moving away from primary and secondary radar systems in favor of space dependent systems like GPS because these legacy radar systems have a large footprint in terms of physical bulk, airlift, and extensive maintenance tail. They are expensive to acquire, certify for use, and maintain.¹¹

Automated Dependent Surveillance-Broadcast

ADS-B is a key component to the FAA's Next Generation Air Traffic Management program (NEXGEN).¹² ADS-B is a concept for aircraft to independently receive GPS and broadcast their precise spatial position and vector data by a digital signal. Anyone with ADS-B receiver equipment, including airborne platforms or ground stations, may receive and utilize this data. The term Automated Dependent Surveillance-Broadcast is based on functionality. ADS-B is automatic: it periodically transmits information without pilot or operator intervention required. It is dependent: position and velocity data are dependent on a global navigation satellite system (GNSS) such as the United States' Global Positioning System. It is a surveillance system: it provides "radar-like" information from participating aircraft. And it broadcasts: it continuously transmits to any other aircraft or ground stations with appropriate receiving equipment.¹³

According to the FAA rule mandating ADS-B avionics for aircraft operating in the United States, ADS-B is a "key component...that will move air traffic control (ATC) from radar-based system to a satellite-derived aircraft location system."¹⁴ This is an advanced surveillance technology that combines an aircraft's positioning source and avionics with a ground

infrastructure to create “the most cost-effective surveillance system currently being implemented around the world.”¹⁵ Because it does not actively illuminate a coverage area like PSR, but rather relies on a response from the aircraft equipment similar to SSR, ADS-B avoids the challenge of clutter or false targets at the expense of seeing only participating aircraft. The positional and vector information has “nearly 10 times more accuracy than radar,”¹⁶ and provides shared information to all participants—aircraft operators and air traffic controllers—in order to improve safety in the sky and on runways and taxiways. Unlike radar, solid state ADS-B sensors are relatively inexpensive and easy to maintain. Manufacturers advertise a cost of 1/10th compared to a radar installation, and maintenance 1/20th compared to a radar system.¹⁷ In typical cost/benefit analysis, the benefits include decreased direct cost, maintenance costs, and replacement costs. They also included operational savings for increased efficiencies of the Air Traffic Management and environmental savings. The greatest savings are from reduced fuel consumption and associated carbon dioxide emissions.¹⁸

The avionics to support ADS-B will be required for Air Force aircraft operating in the United States. According to the rule, this covers “Classes A, B, and C airspace, certain Class E airspace, and other specified airspace.”¹⁹ As mentioned in the introduction, these requirements are anticipated across the globe as more nations strive to capitalize on decreased cost and increased airspace efficiency. There will be two standards for equipment in the United States: the 1090 MHz Mode-S Extended Squitter (ES) broadcast link and Universal Access Transceiver (UAT) broadcast link. The 1090 MHz ES broadcast link has become the international standard for ADS-B. However, it does not support Flight Information Services-Broadcast (FIS-B) due to bandwidth limitations. FIS-B is commonly used to transmit weather, aircraft dispatch, and related flight information to aircraft before departure or during operation. The UAT broadcast

link supports both ADS-B and FIS-B.²⁰ In order to be consistent with international standards, the FAA will require aircraft operating in Class A airspace (at or above 18,000 feet Mean Sea Level) to utilize the 1090 MHz ES. Aircraft below Class A may use either 1090 MHz ES or UAT broadcast link.²¹ Some commercial airlines have already invested in either 1090 MHz ES or UAT broadcast link. The UAT broadcast link also provides weather information for general aviation aircraft which typically operate below Class A airspace. Instead of making a decision that could adversely impact one part of the community more than another, the FAA elected to implement the more expensive dual-architecture to accommodate both systems.²² The FAA rule will require the DoD to meet the same standards as the civilian aviation community and has committed to working with “the appropriate U.S. Government departments or agencies...to develop Memorandums of Agreement to accommodate their national defense mission requirements while supporting the needs of all other NAS users.”²³

Direct benefits to be realized by both DOD and commercial aircraft include optimized altitudes/routing resulting in improved fuel efficiency and reduced CO2 emissions, reduced transit times, and reduced aircraft maintenance costs. This system will also provide reduced separation between aircraft, improved arrival/departure procedures, and new surveillance coverage in previously non-radar areas.²⁴ Reduced separation standards and improved arrival and departure routes have dramatic potential to reduce fuel consumption and operating costs. Continuous descent approaches (CDA) have been tested by United Parcel Service aircraft and will likely be the first near-term opportunity for savings as they do not require reduction in separation standards to achieve fuel efficiencies.²⁵ Once the FAA completes required analysis and safety studies for other options, such as closely spaced parallel approaches or reduced

vertical separation minima, there may be additional areas for the DOD to realize improved routing and fuel efficiencies.

Mode-5/IFF

The largest drawback to the military use of ADS-B is the unencrypted broadcast of aircraft data. ADS-B broadcasts the aircraft positional information unencrypted and can be spoofed by manipulating commercial ADS-B transmitters to send false information while either in-flight or on the ground. However, these limitations may be mitigated in non-permissive environments such as combat operations, by utilizing a combination of ADS-B and Mode-5 Level 2 avionics on the aircraft.²⁶ Mode-5 is the encrypted Identification Friend or Foe (IFF) system used by NATO aircraft to identify themselves to the command and control environment, as well as other aircraft. Because of the small physical size of on-board ADS-B, the Air Force Material Command's Electronics System Center is pursuing a strategy of embedding ADS-B on the same physical card carrying Mode-5 in order to meet the FAA's rule on ADS-B equipment.

²⁷ If ADS-B data were combined with Mode-5 Level 2, creating a Mode-5 Level 2-Broadcast (M5L2-B), it could provide a smooth transition between the permissive (unencrypted air traffic control) and non-permissive (encrypted command and control/air defense) systems.

Furthermore, M5L2-B would fill a currently missing link in the common operational picture between air traffic control and air command and control. A Booze-Allen-Hamilton study of potential M5L2-B application in the Global Air Traffic Management (GATM) system concluded that M5L2-B would facilitate many of the benefits expected of an ADS-B system.²⁸ A demonstration conducted by MITRE for the USAF in 2003 showed that integrating ADS-B data into the military Link-16 architecture greatly improved military pilot situational awareness of general aviation aircraft, thus improving flight safety.²⁹ M5L2-B may be included in the same

datalink architecture to propagate this real-time situational awareness data and voice communication between aircraft, ships, and ground stations.

The advantage of a combined system transmitting ADS-B across the encrypted Mode-5 link is enhanced situational awareness through an improved common operational picture that is currently lacking between air traffic control and military command and control or air defense systems. Commanders in areas such as Afghanistan or Haiti, where the rugged terrain greatly hampers use of conventional radar technologies, would benefit from an ADS-B based air traffic control system to facilitate military and civilian air operations. The screening of mountains and inability of radar to look into valleys without tremendous clutter makes small footprint secondary surveillance systems like ADS-B more ideal for both non-permissive and permissive environments.

Non-Permissive Environments

The 1944 International Air Services Transient Agreement between 129 nations permits certain “freedoms of the air” to include overflight of signatory nations.³⁰ Other nations, such as the People’s Republic of China and Canada,^b also permit overflights via other national agreements, or as negotiated by individual airlines or companies. Unlike these examples, non-permissive airspace is airspace that is either actively denied or of sufficient threat that DOD aircraft do not enjoy freedom of movement. Non-permissive airspace also typically involves uncooperative and unknown targets, which may include both manned and remotely piloted systems, which our considerable air command and control or area air defense assets would be actively tracking.

^b China was never a signatory and Canada withdrew in 1988

Due to the global network of commercial air operations and proliferation of general aviation around the world, it is highly probable that civilian and general aviation aircraft will be a factor in the early and later stages of combat operations, within or overflying contested airspace. It is even more likely to see civilian aviation aircraft mingled with military aircraft in a non-linear battlespace. Therefore, once a majority of aircraft are equipped for ADS-B, receiving ADS-B data into the air command and control or air defense network, and re-distributing over encrypted data links to military aircraft would improve the air battle management, air traffic control, and aircraft commander's situational awareness regarding general and commercial aviation. This data could be correlated against known aircraft movements to reduce the command and control workload. This concept is distinct from carrying ADS-B data for individual military aircraft across the encrypted M5L2-B in that it provides a complete picture of both civilian and military traffic to the command and control network architecture. It would require investment to connect either airborne or deployable ADS-B receivers into the command and control architecture. Permissive environments provide even more pervasive opportunities to utilize deployable ADS-B ground stations to feed air traffic control or command and control systems.

Permissive Environments

ADS-B may be best suited for military use in permissive environments where aircraft are "cooperating" by broadcasting their information. Humanitarian missions, such as that in Haiti, where a natural disaster decimates a nation's air traffic control capability and concurrently imposes a five-fold increase in air traffic management, are particularly suited to a relatively low-cost and quickly deployable ADS-B package to feed the air traffic management system.

Just five days after the Haiti earthquake, the White House issued a press release stating that the airfield capacity was doubled, and that with the Government of Haiti's approval, the USAF air traffic control and airfield management continue to provide service.³¹ At the same time that the White House issued a press report saying we were handling the air traffic on behalf of the Government of Haiti, *The Times* reported "...controllers called a halt to incoming relief flights, unable to cope with the volume of traffic heading to the earthquake zone."³² Clearly, the air traffic management system was insufficient to meet the demands of international relief operations. Haiti was a unique situation, but has some commonalities to other permissive environments in that it was a case of surging air traffic operations without a viable infrastructure to support optimized (radar-like) separation. The airfield itself was in many ways a limiting factor, but it does provide an interesting case to consider, since it was without radar service due mostly to the terrain being impossible for a single sensor to provide good radar coverage. Even if installed on elevations, radar is very poor at looking down due to clutter issues already mentioned. Instead, a multiple-sensor solution like ADS-B could have provided a much better air picture for relief operations to include the abundance of military manned and unmanned systems being employed.

An ADS-B based system would also be well suited to military operations, such as Afghanistan, where airspace control could be rapidly established with a low-maintenance/widely dispersed sensor array. In November 2009, Ambassador Eikenberry issued a cable to Secretary of State Clinton, where he expressed "immediate safety concerns" for both combat and commercial air operations due to the increase in air traffic in Afghanistan and lack of radar-like capability across the country.³³ Non-radar operation, while within ICAO standards, "creates efficiency and economic challenges for airlines...including the thousands of flights that transit

Afghanistan airspace on international routes.”³⁴ In a developing nation such as Afghanistan, aviation overflights and domestic aircraft operations can be the largest sources of income for the government. In Afghanistan, overflights and associated aviation fees represent approximately \$30 million per year of governmental income.³⁵

In such cases as Haiti or Afghanistan, multiple sensor inputs negate screening by mountains and can also overcome the inherent inability of radar to effectively discriminate targets in clutter when the beam is adjusted to look down into valleys or bowls. These hypothetical uses, in areas not currently covered by radar or where radar use would be problematic, may be most revolutionary. ADS-B can, in these cases, provide a radar-like surveillance for air traffic services with strategically located ADS-B ground stations.³⁶

Even though the ground stations for ADS-B are well suited for remote areas that are not suitable for conventional air traffic or command and control radars, no off-the-shelf deployable package yet exists.³⁷ The size and low power consumption would greatly reduce the need for dedicated real-estate on an airfield or forward operating base. The maintenance footprint would also be dramatically reduced, enabling more “boots-on-ground” allocation to shooters, security, or other priorities. The stations themselves are about the size of a dorm refrigerator, and can be located on almost any existing structure. They can be mounted on or alongside government buildings, police stations, or public works and utility structures, taking advantage of existing secure areas. They can also be located on more traditional areas such as airfields, ground/air radio antenna sites, or military structures. Even if located in unsecured areas, the ground stations can blend in with other unobtrusive infrastructure or power equipment. The systems require a stable power source and communications connection either through a network, dedicated circuit, or radio/satellite link to an intermediate location on the network. A study sponsored by

Electronics System Command on combining ADS-B and Mode-5 Level 2 noted that “without the large footprint associated with a deployable RAPCON and its associated radars, a surveillance capability can be established immediately while increasing situational awareness and interoperability.”³⁸

During a preliminary look at the applicability of ADS-B for a deployed environment, the NATO Air Traffic Management Committee (NATMC), Communications, Navigation and Surveillance (CNS) Group came to the preliminary conclusion (currently in uncoordinated draft) that “Technologies enhanced by ADS-B could present potentially more rapid response and cost-effective options for deployable ATM systems. Systems ... could use ADS-B to provide more robust Air Traffic Management (ATM) services in austere environments, such as humanitarian response where a catastrophe has damaged the ATM infrastructure.”³⁹

Conclusion and Recommendation

A suite of deployable ADS-B sensors networked into both air traffic control and command and control networks would greatly increase situational awareness for commanders, controllers, and aircrew across the spectrum of operations, from permissive humanitarian operations to non-permissive combat operations. A deployable ADS-B sensor suite designed for remote areas would need only stable power and connectivity to the network, which can be achieved through any number of radio/data or satellite links if not co-located with the control facility. The physical size also makes it more economical for procurement, sustainment, and deployment of multiple sensors to be utilized in areas such as the mountainous regions of Afghanistan where radar coverage is not effective due to clutter and terrain screening. ADS-B

will enable controllers to safely control participating aircraft with reduced separation standards in areas that currently require up to 80NM separation under non-radar rules for safe operations.

Utilizing the ADS-B data within the air command and control architecture will increase air battle manager and pilot situational awareness and reduce the seams between air traffic control and air command and control by providing a more common air traffic picture. Some of the limitations to crossing the unclassified air traffic management network to the classified air command and control network may be overcome by sending the ADS-B data across the encrypted M5L2 systems. The M5L2 has the excess capacity in its data stream to send the more accurate ADS-B data without hampering its current functionality. Since the program office is embarking on an ADS-B acquisition strategy of co-locating the circuitry on a common card between the two systems (ADS-B and M5L2), this appears to be technologically feasible.

There is clearly an opportunity to utilize this new class of mandated equipment to create a deployable air traffic control system that can feed legacy and future control facilities. Combined with M5L2-B, it can also provide improved situational awareness through the air command and control network. Other benefits to the warfighter include reduced footprint, manpower, airlift requirements, and lifecycle costs. Because ADS-B is the key to the FAA's NEXGEN Air Traffic Management program and has also been mandated by other nations, this is a prime opportunity to use this technology to improve deployed air traffic control and air command and control capabilities.

¹ Emma, *Australian in World First For Nationwide ADS-B Coverage*, 1.

² Babbitt, *Automatic Dependent Surveillance-Broadcast*, 45.

³ CFR, Title 14, Chapter 1, Subchapter B, Part II-*General Rulemaking Procedures*.

⁴ Transport Canada, AC 700-009, *Automatic Dependent Surveillance-Broadcast*, 4.

⁵ ADS-B Technologies, *Shadow of the Great Wall*, 1.

⁶ United Arab Emirates, General Civil Aviation Authority, *H.H Sheikh Mohamed*, 1.

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- ⁷ Alan Storm (Chief, Civil/Military Integration, Headquarters, USAF/A3O-BA), in discussion on draft with author, 6 December 2010.
- ⁸ FAA Joint Order 7110.65T, *Air Traffic Control*, Chapter 6.
- ⁹ ICAO Separation and Airspace Safety Panel, *Operational Use of ADS-B*, 1.
- ¹⁰ Babbitt, *Automatic Dependent Surveillance-Broadcast*, 54.
- ¹¹ HQ FAA/ATO, *ADS-B Frequently Asked Questions*, 1.
- ¹² HQ FAA/ATO, *Surveillance and Broadcast Services*, 1.
- ¹³ NATO NATMC CNS Group, *Draft NATO Position on ADS-B*, 1-2.
- ¹⁴ Babbitt, *Automatic Dependent Surveillance-Broadcast (ADS-B)*, 15.
- ¹⁵ ICAO Separation and Airspace Safety Panel, *Operational Use of ADS-B*, 2.
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- ²⁰ Ponticel, *NextGen Advances With New ADS-B Rule*
- ²¹ *Ibid.*, 19.
- ²² *Ibid.*, 25.
- ²³ *Ibid.*, 29.
- ²⁴ Hu, *Technology Transition National Airspace Transportation System*, 58.
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- ³⁴ *Ibid.*, 4.
- ³⁵ USAF CENTAF, *Business Plan for Upper Airspace Management in Afghanistan*, 5
- ³⁶ Air Traffic Management Advisory Committee, *Use of Legacy Equipment Before 2020*, 18
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